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Creation of a Ceramics Handbook -
Second Quarterly Report

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Research Status

Research to date has been generally confined to the massive literature searches performed through our library, but largely through the North Carolina Science and Technology Research Center where incipient results began en masse in early March from the following files:

<u>File Name</u>	<u>Approximate Entries Searched</u>
National Aeronautics and Space Administration	700,000
U. S. Government Reports Announcements	200,000
Engineering Index	450,000
Chemical Abstracts Condensates	600,000

Two gratis searches were performed for the project, one through the Jet Propulsim Laboratory and the other by Martin Marietta Corporation Orlando Division, for which the project is gratefully indebted.

Hundreds of Documents Abstracts have been reviewed and ordered on Microfiche, wherever possible, in view of hardcopy costs and that selection process continues.

Xerox and similar hardcopy processes are accepted as a second choice.

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A large set of literature is growing on all selected candidates and already a graphical scheme exists for plotting the appropriate data on digital printout paper. Least squares routines will be coupled with these plots to generate both analytic and graphical output of all pertinent property information versus independent variables as temperature and density.

Also, when raw fracture information is available, Weibull distributions will be correlated with such data which considers the biaxial fracture characteristics of such a material. To this end, the enclosed paper is addressed and reproduced in full as presented at the twelfth Symposium on Electromagnetic Windows co-authored by William J. Craft and Juri G. Filatovs. It is also of some interest that past projects of this type to accumulate ceramic material property data have not generally included information on the acquisition and compilation of fracture/failure models. Statistical and numerical analysis techniques are being utilized which will accept tabulated data and produce models of this type.

Creation of a Ceramics Handbook

William J. Craft

and

G. Juri Filatovs

North Carolina A. & T. State University is the recipient of a grant, NGR 34-012-013, through the Jet Propulsion Laboratory, Pasadena, California, for research leading to the development of a Ceramics Handbook defining properties and parameters necessary for thermostructural design. This paper describes work currently underway toward this goal and in particular toward the evolution of a reliable predictor of fracture from current literature. Ceramics suppliers, users and those engaged in its characterization are being asked to share recent results.

The characterization and use of ceramics has been the subject of no less than 1,200 publications in the past ten years, the majority appearing since 1968. This unusual interest in such inherently brittle materials can be explained by their many desirable properties such as resistance to heat, oxidation, and corrosion providing various nuclear, optical, magnetic and electric applications.

In spite of such massive research efforts, interpretable property data remains sparse. The literature on ceramics, while vast, is also vastly confusing. A polycrystalline ceramic is usually made up of one or more phases, grains and pores of various sizes and distributions, and impurities inside the grains and in the grain boundaries. All of these, in addition to the processing, influence the properties of a ceramic.

Another obstacle to the wider utilization of ceramics is that they usually fail catastrophically in the tensile mode (1). At present, the only satisfactory way of coping with this brittleness is by gross overdesign and limiting ceramics to areas where structural functions have secondary consideration (2).

Structural design of ceramics with confidence approximating that of metals is virtually unknown. Two standard deviation units from the average tensile strength mean can even give a negative value due to the pronounced scatter.

If practical literature data exists it is either frequently not readily interpretable for the designer or it may be contradicted by other publications. Simple fracture stress value data as well as fracture mechanics theories vary widely. For alumina, a standard refractory oxide, tensile strength test results can differ by a wide margin (3,4). There is also disagreement among experts as to which variables are important and to what extent they bear on the properties of ceramics. For instance, several researchers have differed on the physical property interaction with surface finish in alumina. H. S. Starrett (5) suggests little correlation between strength and finish while H. P. Kirchner et al., (6) feel this is a major fracture stress level predictor.

Actually, surface flaws interacting with the type of finish, if surface effect predominates, should pronouncely weaken a specimen subject to testing where the outer fibers sustain a large part of the load as with simple flexure or torsion as opposed to uniaxial tension. It is frequently found that uniaxial tension testing produces lower strength results than any other standard test of a brittle material contradicting this hypothesis or indicating alignment strains which admittedly can be important in brittle materials with low fracture stress to modulus ratios.

Starrett found the Weibull statistical model of volumetric flaw distribution linking fracture to the integrated probability of failure from the local uniaxial stress level suitable for his results (7). This theory also explains why a larger specimen of like material will fail at lower stress levels than smaller ones and why tensile specimens exhibit lower apparent strengths than flexure ones. In practice, such a theory, while important, may not be strictly applicable as exercised to date due to the general presence of more than one non-zero component of the stress tensor. In isotropic homogeneous materials used as thin shells where in-plane stresses predominate, the stress tensor form required is $(\sigma_x, \sigma_y, \tau_{xy})$ which can be specified by principal direction components (σ_1, σ_2) fully characterizing the fracture surface. Fortunately this covers many cases of practical interest such as thermally stressed pressure vessels, rocket nozzles, and radomes (8). The general stress tensor contains six independent components, Fig. 1, but a switch to principal direction coordinates reduces the variables to three, Fig. 2. being sufficient for the study of most fracture criteria. Clearly a statistical model making use of the 'distance to fracture' may be the preferred criterion for failure as displayed by the fracture surface, Fig. 3. This ubiquitous problem should be one of the most important questions to be investigated under this NASA-JPL grant entitled 'Creation of a Ceramics Handbook'.

Clearly, to answer all questions required in the complete characterization of ceramics as provided by extensive literature searches is an impossible task. For this reason and because several interesting materials exist which find wide-spread use and for which reasonable characterization data is known, five candidates, alumina, magnesium oxide, silicon nitride, slip cast fused silica, and silicon carbide, have been chosen from among them.

Already several hundred papers are being researched and it is hoped that by December a series of property data curves will be available so that a designer faced with a thermomechanical problem can provide input to an analytical solution, estimate, or finite element computer program and then consult a proper fracture model or at least a recommended one. In this way it is to be hoped that a reliable factor of safety or other meaningful measure of design quality can be assessed.

This investigation was initiated December 1, 1973 and proposes to draw on industry and academic expertise, and to that end, sweep letters are being issued to major researchers, manufacturers, and users asking that existing but perhaps unpublished data be shared. Other properties, equally important to design use include radar parameters, chemical compatibility, temperature dependences, vapour pressure, heat capacity, conductivity, porosity, and catalytic ability. The handbook will be heavily referenced and will contain cross-indexing so that information is available under specific candidates and properties in a matrix arrangement.

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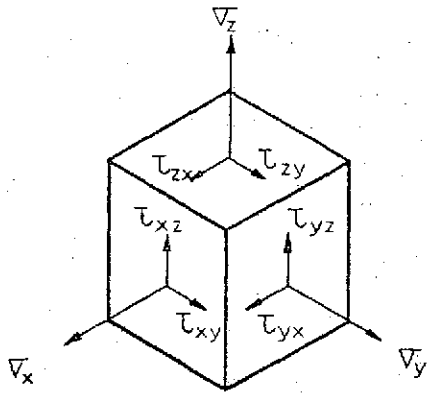


FIG.1- ARBITRARY AXES

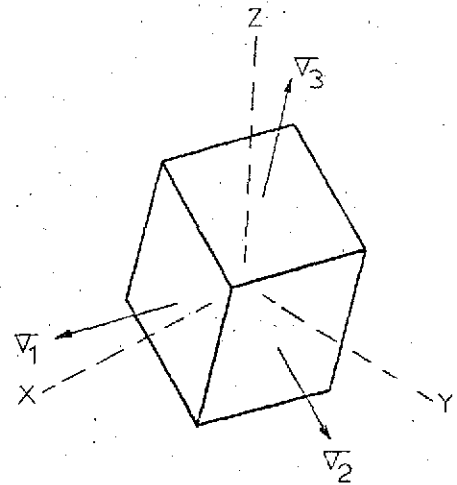


FIG.2- PRINCIPAL AXES

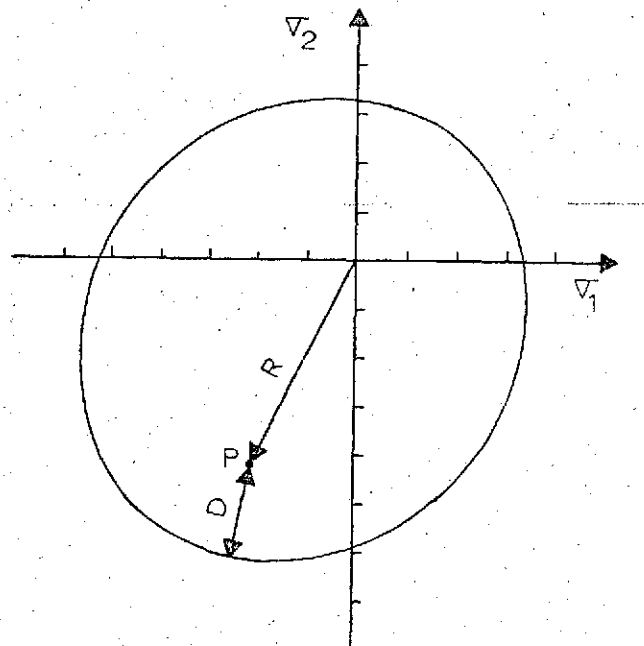


FIG.3- FRACTURE SURFACE
P=Stress state
D=Distance to fracture
R=Load path